FTS Maintenance and Calibration at DSS 42/43

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An FTS maintenance and calibration task was conducted at DSS 42/43 during August 1978. The objectives of this effort were (1) the routine maintenance and calibration of hydrogen masers, (2) installation and calibration of cesium standards, (3) installation of test equipment for frequency measurement, (4) CRG testing, (5) cabling inspection and repair, (6) check thermal and magnetic environment of H-maser/cesium room, and (7) calibration of frequency and timing subsystem.

I. Introduction

During August 1978, an FTS maintenance and calibration effort was organized by the station director at DSS 42/43. The objectives of this effort were (1) the routine maintenance and calibration of hydrogen masers, (2) installation and calibration of cesium standards, (3) installation of test equipment for frequency measurement, (4) CRG testing, (5) cabling inspection and repair, (6) check thermal and magnetic environment of H-maser/cesium room, and (7) calibration of frequency and timing subsystem. This report describes the work accomplished in these areas.

II. Routine Maintenance and Calibration of Hydrogen Maser System

Work on the H-maser was given top priority because of the frequency settling period required after the physics package is serviced. With the exception of an uninterruptable power supply (UPS) failure, the DSS 42/43 H-maser had run uninterrupted for two and one-half years. This particular maintenance interval was chosen over the standard three-year interval because of Voyager commitments.

All H-maser system operating parameters were tested before the physics package maintenance was started. These tests included:

(1) Checkout of all electronic monitoring, control and synthesis circuits.

(2) Checkout of optical alignment of atomic beam.

(3) Observation of cavity Q, loaded and unloaded.

(4) Measurement of atomic line Q.

(5) Measurement of magnetic shield gaussing effects.

(6) Checkout of long- and short-term system frequency stability against cesium and rubidium standards.

The only adjustment necessary was to realign the 100-MHz voltage-controlled oscillator, which had drifted slightly in frequency. This misalignment affected the period necessary for the post receiver phase lock loop to reacquire lock after a major frequency change was set into the system by the master synthesizer. All other maser system parameters were within the DSN specified limits.

The physics package was then vented to atmospheric pressure with dry nitrogen and the ion vacuum pump elements were changed. The physics unit was reevacuated and the atomic beam optics realigned. Maser frequency settling was monitored over a four-day period. This frequency transient occurs because of the disturbance to the physics package thermal equilibrium.

III. Installation and Calibration of Cesium Standards

A Hewlett Packard cesium standard (Model 5061A) with the high-performance tube (option 004) was installed in the H-maser room. The Cs standard was degaussed as per H.P. specification and the output levels were checked. After degaussing, the Zeeman frequency was checked and compared to the original calibration number supplied by the timing standards laboratory of the Goldstone Deep Space Complex. The Zeeman frequency agreed with the original calibration and all system parameters were within H.P. specifications.

IV. Installation of Test Equipment for Measurement of Long- and Short-Term Frequency Stabilities

A Tracor 895-A linear phase and time comparator was installed to monitor long-term frequency stability. This equipment was used to intercompare the two stations' rubidium standards vs the cesium standard vs the hydrogen maser. The Tracor allowed any two standards to be compared; therefore, switching and time sharing were necessary for an overall comparison.

The autotuner was installed as an integral subsystem of the H-maser monitoring and control system. The autotuner's primary function is to tune the microwave cavity resonant frequency to the atomic hydrogen transition frequency. This tuning function is performed at regular intervals to remove long-term drift caused by thermal and mechanical changes of the microwave cavity.

The theory and operation of the automatic cavity tuner are discussed in Section VIII.

V. Coherent Reference Generator (CRG) Testing

Work was carried out on the CRG equipment concurrently with checkout of the new cesium standard and refurbishing of the H-maser. The CRG switching and status functions were first isolated by supplying the distribution amplifiers and the FTS clocks directly from rubidium standard No. 1. The CRG was reconfigured in this manner to provide the station with its regular FTS inputs while the CRG switching functions were being tested.

The following work was carried out:

(1) The coax switches which select the 0.1-, 1.0-, 5.0-, and 10-MHz sources were exercised from the H_1 and H_2 switches. No problems were observed.

(2) A failed LED status light in the control and status panel was replaced.

(3) Reasons for other status light indications of failure from various distribution amplifiers were investigated.

(4) Switching transients on the 1-MHz switch module output were checked and recorded. A Tektronix 466 storage oscilloscope was used as the monitoring device. The wave form and trigger source test points were listed on JPL drawings No. 9455669 and 9459378 respectively. The aim of this exercise was to look for transients in the output of the 1-MHz clock reference switch assembly when switching between two sources (hydrogen maser and cesium frequency standards). Past experience has shown that there is a significant chance of loss of FTS clock synchronization when manually switching between time reference standards. These sources were connected to input ports such that by switching between HM_1 and HM_2 source select buttons on the CRG status and control panel, the desired transition between these two standards could be observed at the clock reference assembly primary output. The phase difference indicated on the Fig. 1 diagrams was measured at the primary and secondary outputs of the 1-MHz clock reference switch assembly and is an approximate value. The diagrams are freehand sketches of the single scan transient waveforms. The observed frequency is 1 MHz; the time-base setting was 1 μs/cm and the vertical gain was 0.5 v/cm. A delayed trigger mode was necessary to observe the transitions which occurred randomly around two fixed delay times. The delay time for switching from HM_1 to HM_2 was approximately 185 μs. The delay time for switching from HM_2 to HM_1 was approximately 70 μs. The observed waveform also depends largely on the phase of the two sources with respect to the time of switching. Note that 0° phase difference resulted in a nonobservable switching transient.

(5) Efforts were made to check switching transients in the 1-MHz output due to failure of the prime standard. These attempts were unsuccessful in the time available.

VI. Repair and Recabling of Portions of FTS

The type N cable connectors were replaced on all of the H-maser pressurized hardlines. These connectors had been a constant source of leaks in the dry nitrogen pressurized cable runs. The cable run between the H-maser/cesium distribution to the CRG was shortened and rerouted. All cables in this system were mechanically inspected and electrically checked for proper characteristic impedance with a time domain reflectometer. The cable connections are in agreement with DSN specifications.

VII. Check Thermal and Magnetic Environment of H-Maser/Cesium Room

Temperature variations in the room were measured and recorded with the Hewlett Packard 2801A crystal thermometer, D to A converter and a strip chart recorder.

With the door to the room left open, temperature variations of 3°C peak to peak were observed. Turning the overhead lights on in the room caused the temperature to rise approximately 1°C. With the lights off and the door closed, a diurnal drift of 1.3°C peak to peak was observed. The magnetic changes in the room were measured with an RFI fluxgate magnetometer. The magnetometer probe was stationed in three positions as shown (Fig. 2); B and C are perpendicular to axis A and to each other. The axial position A was the most sensitive to magnetic changes. The diurnal magnetic change in the room varied approximately 1.5 milligauss P to P.

The movement of magnetic equipment in the surrounding area had a much greater effect on field measurements. An 8 milligauss peak was observed by shifting magnetic tape racks in the overhead adjacent tape storage room. A peak of 2 milligauss was noticeable by swinging out the carpool status board in the office directly overhead.

VIII. Calibration of FTS for Frequency Stability and Accuracy

Temperature drifts and mechanical changes cause H-maser cavity frequency displacements which must be periodically corrected (Ref. 1). To maintain long-term maser frequency stabilities of one Q part in 10^{-14}, the resonant frequency of the 1420-MHz maser RF cavity must be maintained within 0.5 Hz. If a periodic cavity retuning scheme were not employed, a 10^{-14} maser stability requirement would dictate that cavity dimensions must be maintained within 10^{-10} and cavity temperature must be controlled within 0.003°C. In the long term (days/months), these tolerances on dimensional and thermal stability are not practical.

Another possible source of long-term frequency drift could be the physical change of the Teflon coating in the atomic storage bulb. This coating is constantly bombarded by highly reactive atomic hydrogen and ultraviolet from the atomic hydrogen source.

There is physical evidence of this wear phenomenon in storage bulbs out of masers that have been operated over a long term, i.e., greater than 4 years. This erosion of the storage bulb coating could cause a long-term frequency drift by changing the atomic and wall shift.

The automatic cavity tuner (autotuner) was developed to periodically retune the maser RF cavity to the atomic transition frequency. The quantitative effect of cavity pulling of the maser output frequency is given by (Ref. 2):

$$f_n - f_0 \approx (f_n - f_c)\frac{Q_c}{Q_L}$$

where

f_n = the atomic hydrogen transition frequency ($\approx$1.420 $\times 10^9$ Hz)

f_0 = the maser oscillation frequency caused by f_c

f_c = the cavity resonance frequency

Q_c = the cavity frequency divided by its bandwidth ($\approx$45,000)

Q_L = the atomic hydrogen transition frequency divided by its linewidth ($\approx 1.4 \times 10^9$)

Therefore, the maser output frequency is pulled by the cavity resonance frequency by the ratio of O_c/Q_L (10^{-4} to 10^{-5} dependent on atomic storage time). The most acceptable maser cavity tuning method (Ref. 2) is to increment the transition linewidth and adjust the cavity frequency f_c such that this increment in linewidth does not change the output frequency. The cavity frequency is then centered upon the atomic transition frequency in such a manner that the least amount of cavity pulling occurs.

A block diagram of the autotuner servo system is shown in Fig. 3. The autotuner modulates the hydrogen transition linewidth by limiting the supply of hydrogen atoms to the cavity oscillator assembly. This feat is accomplished by moving a mechanical vane into the atomic beam, thereby limiting usable atoms to the storage bulb. The decrease of atoms from the atomic source increases the lifetime of excited atoms in the storage bulb by reducing the collision factor. The atomic transition Q_L increases as the linewidth decreases.

The cavity is tuned by a varactor connected through a directional coupler to the cavity coupling loop. The period of the beat frequency between the H-maser and a frequency reference (R_{B_1} at DSS 43) is measured to determine incremental frequency change produced by changing the atomic transition linewidth. This frequency change is registered in count time by the autotuner, which then sends a proportionate voltage to the varactor to cancel this frequency offset. The autotuner continues to integrate this frequency/varactor voltage function to 0. The oscillator cavity is then tuned to the atomic transition.

The DSS 43 H-maser was autotuned using rubidium No. 1 as a reference clock. A 100-second "0" cross-averaging period was set in by shifting the H-maser master synthesizer. This 100-second count was chosen because it is the best averaging period for a rubidium standard, i.e., at least 5×10^{-13}/100 seconds as per Hewlett Packard specification.

There were two major problems encountered with the autotuning subsystem.

(1) The autotuner was false triggering on the start of the count period. Upon investigation of the problem a 1-kHz pulse was detected riding on the 0 crossing input. This 1-kHz pulse appeared randomly and was being fed back by the autotuner's internal 1-kHz generator. A 200 P.F. bypass capacitor was installed in the 0 crossing input circuit to shunt this transient pulse. This modification eliminated the false triggering.

(2) The autotuner's servo loop gain control switches in decade steps. The 3-position switch in its lowest gain position would take a month to integrate the H-maser to a tuned point using a rubidium as a clock reference. The medium gain position which is used for maser vs maser tuning has too much gain for rubidium vs maser tuning.

The 100-second average for a H-maser is approximately two orders of magnitude more stable (5×10^{-15}) than that of a rubidium. The rubidium's added noise for these short-term counts causes the servo loop to overshoot and hunt.

The maser tuning was accomplished by comparing autotuner data to manual tuning numbers and averaging. This decade stepping loop gain control switch should be replaced with a Vernier control. Then each tuning situation may be optimized to the upper noise limits of the standard with the poorest short-term stability.

A. Stability

The data in Table 1 were taken with the Tracor comparator and the H-maser autotuner. The 5-MHz output from the cesium and rubidium standards were multiplied to 100 MHz while being compared to H-maser for short term tests. Both rubidium standards maintained mid-range parts in 10^{-12} for 4 hour runs.

The best long term data was taken at 5 MHz between the H-maser/cesium over a thermally and magnetically quiet weekend. The total frequency drift between both standards was 3.4×10^{-13} for a 48-hour period, which is a time shift of 60×10^{-9} seconds. The H-maser master synthesizer was set to the calibrated cesium frequency. The station rubidiums will be set to the cesium frequency when tracking schedules permit.

B. Conclusion

The most cost effective methods for improving the stability of the FTS are:

(1) Provide a thermally and magnetically stable central environment for all frequency standards.

(2) Modify electronic switching functions of the CRG.

(3) Control all cabling and distribution functions from the central standards room to the user.

(4) Place all frequency and timing functions on the U.P.S.

Acknowledgment

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References

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Table 1. Short-term 100 MHz/vs hydrogen maser averaging time: 100 seconds

HP5061 Option 004 Cesium	HP5065A No. 1 Rubidium	HP5065A No. 2 Rubidium
6×10^{-13}	2.3×10^{-13}	3.4×10^{-13}

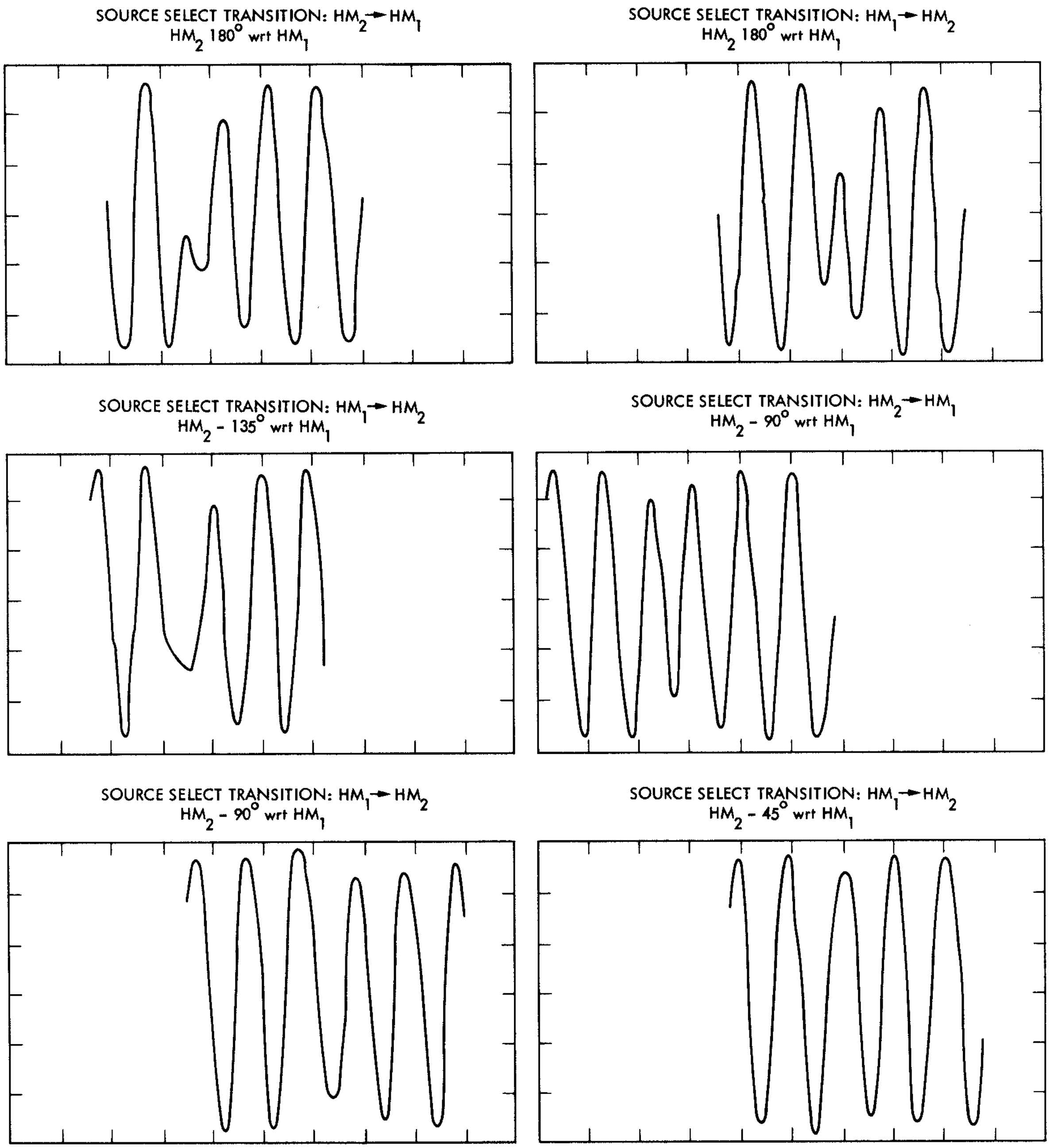
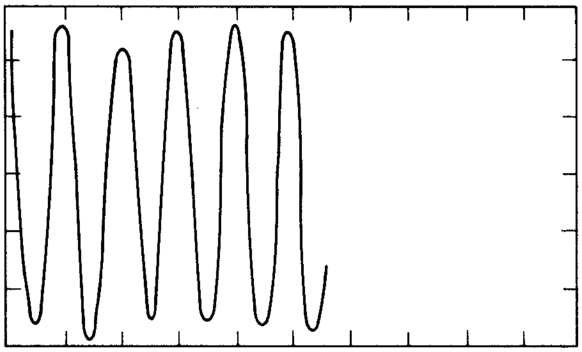
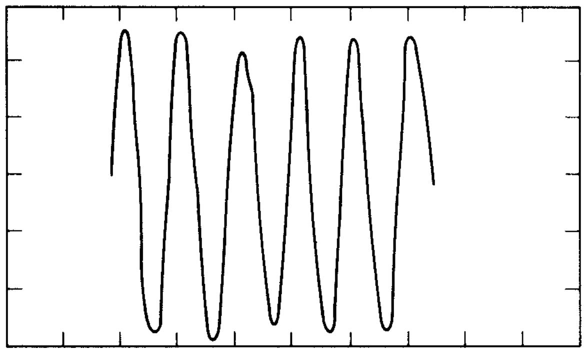


Fig. 1. Phase difference diagrams

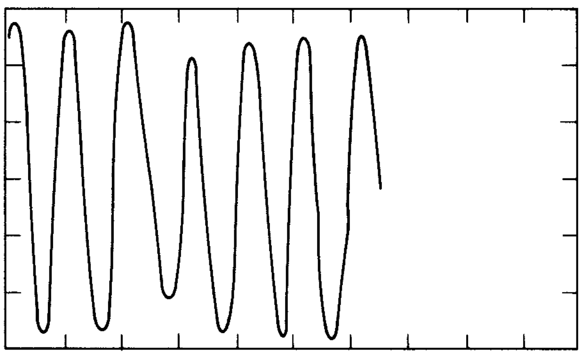
SOURCE SELECT TRANSITION: $HM_2 \rightarrow HM_1$
$HM_2 + 45^\circ$ wrt HM_1



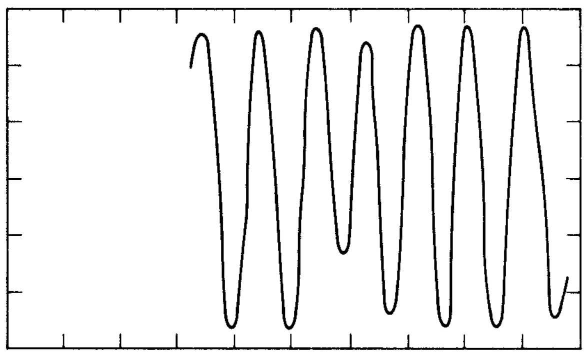
SOURCE SELECT TRANSITION: $HM_1 \rightarrow HM_2$
$HM_2 + 45^\circ$ wrt HM_1



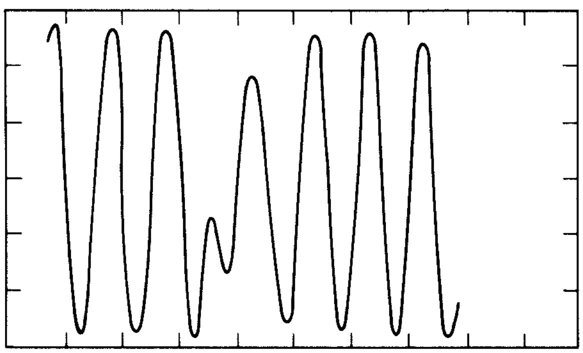
SOURCE SELECT TRANSITION: $HM_2 \rightarrow HM_1$
$HM_2 + 90^\circ$ wrt HM_1



SOURCE SELECT TRANSITION: $HM_1 \rightarrow HM_2$
$HM_2 + 90^\circ$ wrt HM_1



SOURCE SELECT TRANSITION: $HM_2 \rightarrow HM_1$
$HM_2 + 135^\circ$ wrt HM_1



SOURCE SELECT TRANSITION: $HM_1 \rightarrow HM_2$
$HM_2 + 135^\circ$ wrt HM_1

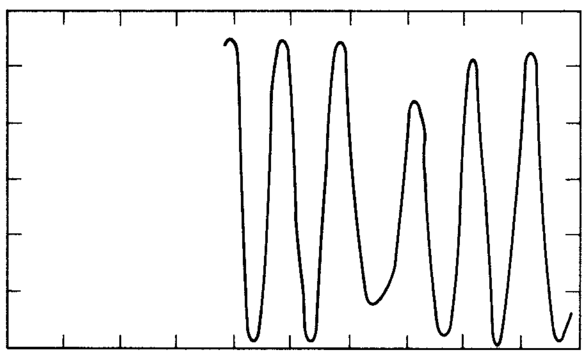


Fig. 1 (contd)

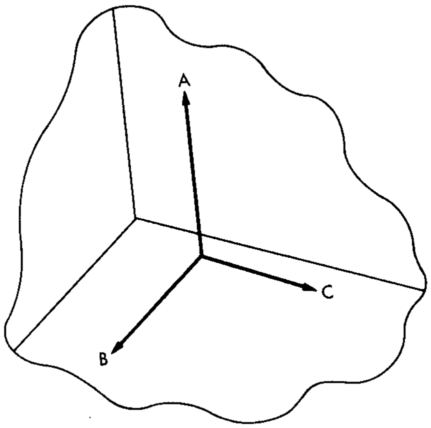


Fig. 2. Magnetometer probe axial orientation

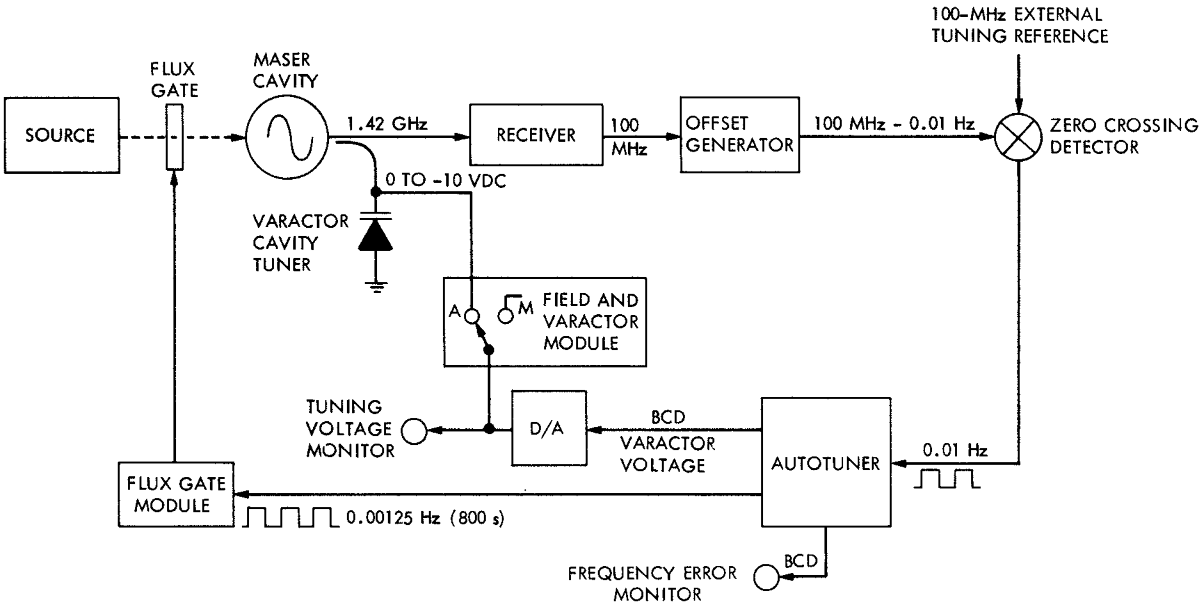


Fig. 3. Autotuning block diagram